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Swift Observations of Gaia BH3

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Abstract

We present UV and X-ray observations, obtained with the Swift Observatory, of Gaia BH3, a binary system containing a 33 $M_\odot$ black hole discovered through Gaia astrometry. The system is well detected in all UV and optical filters (1700–6500 Å). We compare our results with the modeling of the noncollapsed component using synthetic stellar libraries, and a good agreement is found with our UV observations.

Unified Astronomy Thesaurus concepts: Stellar mass black holes (1611); Astrometric binary stars (79); Ultraviolet astronomy (1736); G giant stars (557)

1. Introduction

Gaia BH3 (Gaia DR3 4318465066420528000) is an astrometric binary system containing a 33 $M_\odot$ dormant black hole, discovered through astrometry by the Gaia mission. The binary system has a period of 11.6 yr, eccentricity $e = 0.729$, a semimajor axis of 16 au, and a distance $d = 590$ pc. The visible component is a metal-poor giant of mass $M = 0.76\,M_\odot$, $T_{\rm eff} = 5200$ K, $\log(g) = 2.929$, and [Fe/H] = −2.56 (Gaia Collaboration et al. 2024).

Gaia BH3 is a remarkable source because the mass of the unseen black hole component is significantly larger than that of black holes in X-ray bright systems, the most massive of which is Cyg X-1, $M = \sim 20\,M_\odot$ (J. C. A. Miller-Jones et al. 2021).

In this work we report on UV and X-ray observations of Gaia BH3 obtained with the Neil Gehrels Swift Observatory.

2. Swift Observations

Swift observed Gaia BH3 in 2024 March–April within Target of Opportunity programs (ObsIDs 00016607001, PI J. Miller; ObsID 00016607001, PI B. Sbarufatti) for a total exposure of ∼6 ks. The observation journal and results are reported in Tables 1 and 2. X-ray Telescope (XRT; D. N. Burrows et al. 2005) and UV and Optical Telescope (UVOT; P. W. A. Roming et al. 2005) data were analyzed using the standard software packages included with HEASOFT (version 6.33.2) and applying the relevant release of the calibration database. The XRT and UVOT *U* and UVM2 filter images are shown in Figure 1.

2.1. X-Ray Observations

The XRT data of each observation were processed using the *xrtpipeline* task with standard calibration parameters. A search for X-ray sources consistent with the sky position of BH3 was performed using the XIMAGE detection algorithm on both data sets, with no source detected in either case, with a 90% confidence level. We then combined the observations using XSELECT and confirmed that no source coinciding with Gaia BH3 is detected. Using a 30 pixel (70.″8) radius region for BH3, we estimate an upper limit of 8.1×10^{-3} counts s^{-1} (4.0×10^{-16} W m^{-2}, assuming a power-law spectrum with photon index $\Gamma = -2$). This is consistent with, but less constraining than, the results of eRosita ($F_{\rm X} < 1.2 \times 10^{-17}$ W m^{-2}, M. Gilfanov et al. 2024) and Chandra ($F_{\rm X} < 3.25 \times 10^{-18}$ W m^{-2}; N. Cappelluti et al. 2024).

An X-ray source is serendipitously detected in the field, at position R.A., decl. (J2000): 19 hr 39′09.15″, +15°01′21.7″, with an error radius of 6.″4, at a rate of $3.3 \pm 0.8 \times 10^{-3}$ counts s^{-1} (equivalent to a flux of $1.6 \pm 0.4 \times 10^{-15}$ W m^{-2} assuming a power-law spectrum with photon index $\Gamma = -2$). No known source is reported by the SIMBAD database (M. Wenger et al. 2000) or the NASA/IPAC Extragalactic Database (NED)[4] inside the XRT error circle.

2.2. UV Observations

In order to characterize the optical/UV spectral energy distribution (SED) of the source, UVOT observations were obtained, with a first pointing in 2024 April using all six standard filters (T. S. Poole et al. 2008; A. A. Breeveld et al. 2011) and a second deeper pointing using only the UVM2 filter in 2024 May (see Table 2).

A list of all sources detected in the images was produced using the *uvotdetect* tool to aid selection of a source and background region not contaminated by other sources. Multiple exposures in the same filter were coadded using the *uvotimsum* task, and aperture photometry was obtained using *uvotsource*, using a 5″ radius aperture region centered at the Gaia BH3 position and an empty background region of 25″ radius.

The source was detected in all six UVOT filters. Data of the *B* filter are strongly affected by saturation and therefore ignored. *U* and *V* filter data show some evidence of coincidence loss that was corrected using the appropriate corrections available in the UVOT calibration database while running *uvotsource*, despite a higher uncertainty on the estimated fluxes for those bands. The UVW1 and UVW2 filters are contaminated by a red leak, which we corrected following the prescriptions suggested by P. J. Brown et al. (2010). The derived UV fluxes are given in Table 2. The UVM2 data across the two epochs show no evidence of variability.

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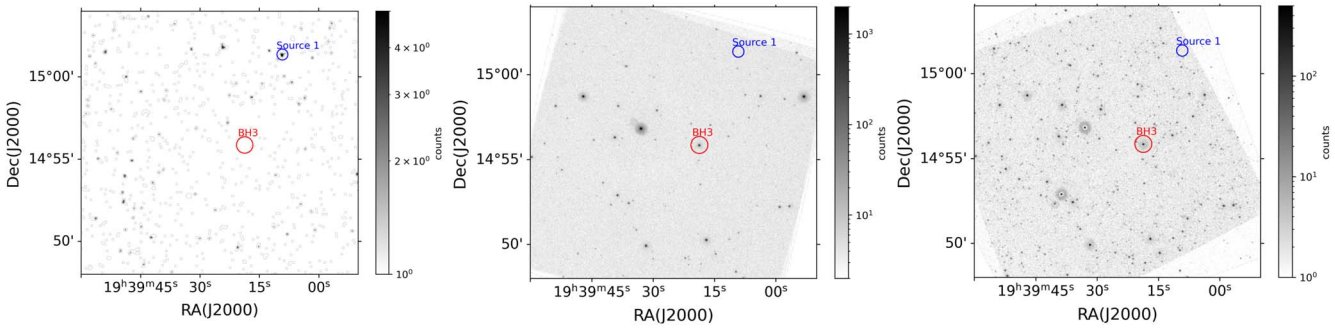


Figure 1. Swift XRT (right), UVM2 (center), and *U* (left) of the field of BH3. XRT: the positions of BH3 and the region used to estimate the upper limit are shown as a red circle. The blue circle shows the position of the only X-ray source serendipitously detected in the field. UVOT: the red circles show the position of BH3, while the blue circle shows the position of the serendipitous X-ray source. The color bars show the raw image counts.

Table 1
Swift XRT Observations of Gaia BH3

Date	Exposure (s)	0.3–10 keV Flux (10^{-15} W m $^{-2}$)
2024-04-19	1379	<1.4
2024-05-25	4555	<0.57

Table 2
Swift UVOT Observations of Gaia BH3

Date	Exposure (s)	Filter	Wavelength (nm)	Flux (10^{-16} W m^{-2} nm^{-1})	Model Flux (10^{-16} W m^{-2} nm^{-1})
2024-04-19	437	UVW2	192.8	0.15 ± 0.02	0.11
2024-04-19	327	UVM2	224.6	0.32 ± 0.01	0.30
2024-04-19	218	UVW1	260.0	1.10 ± 0.05	1.02
2024-04-19	109	*U*	346.5	3.8 ± 0.2	3.59
2024-04-19	109	*V*	546.8	8.5 ± 0.2	8.21
2024-05-25	4478	UVM2	224.6	0.310 ± 0.007	0.30

3. Synthetic Spectrum

In Figure 2 we report, along with our UVOT data and the Gaia XP spectrum (Gaia Collaboration et al. 2023), a simulated spectrum, obtained using the YBC database[5] and its interpolation code (Y. Chen et al. 2019), based on the PARSEC isochrones (A. Bressan et al. 2012), assuming the physical parameters for the noncollapsed component given by Gaia Collaboration et al. (2024; see also Section 1) and using the PHOENIX spectral libraries (F. Allard & P. H. Hauschildt 1995; F. Allard et al. 1997). The reddening was taken into account following J. E. O'Donnell (1994) and J. A. Cardelli et al. (1989) with $A_V = 0.76$. It is apparent that the good agreement between observations and the synthetic spectrum reported by Gaia Collaboration et al. (2024) in the visible and near-infrared bands extends also in the UV up to ∼1600 Å (Figure 2). No indication of a UV excess is present. The predicted broadband fluxes are also reported in Table 2.

4. Discussion

Gaia BH3 is the third black hole discovered through precise astrometric measurements by Gaia (for BH1 and BH2, see S. Chakrabarti et al. 2023; K. El-Badry et al. 2023a, 2023b; A. Tanikawa et al. 2023). The discoveries appear rather robust because the astrometric procedure is unaffected by the uncertainty on the inclination angle.

These systems are much wider than those of classical X-ray binaries, so accretion and electromagnetic emission powered by Roche-lobe mass transfer can be excluded. A possible energy source could be the accretion of the interstellar medium. We quote the case of OGLE-2011-BLG-0462 (K. C. Sahu et al. 2022), where an isolated black was discovered in Hubble Space Telescope images through gravitational microlensing. Also, in that case, it was possible only to give an upper limit to the X-ray flux (S. Mereghetti et al. 2022). Another likely accretion mechanism is an advection-dominated accretion flow due do wind-driven mass loss from the companion star, which has already been considered by N. Cappelluti et al. (2024) for this system but has also been proposed for BH1 and BH2 by A. C. Rodriguez et al. (2024).

In the present work we focus on Gaia BH3 and the UV band properties of the binary system in search of a possible UV contribution from the black hole to the total emission. Our observations do not show any significant UV flux in excess with the expected values from the model constrained at lower frequency. This is consistent with the expectations of N. Cappelluti et al. (2024), who proposed an advection-dominated accretion flow emission model for the accretion of Gaia BH 3.

[5] Available at https://sec.center/YBC/index.html.

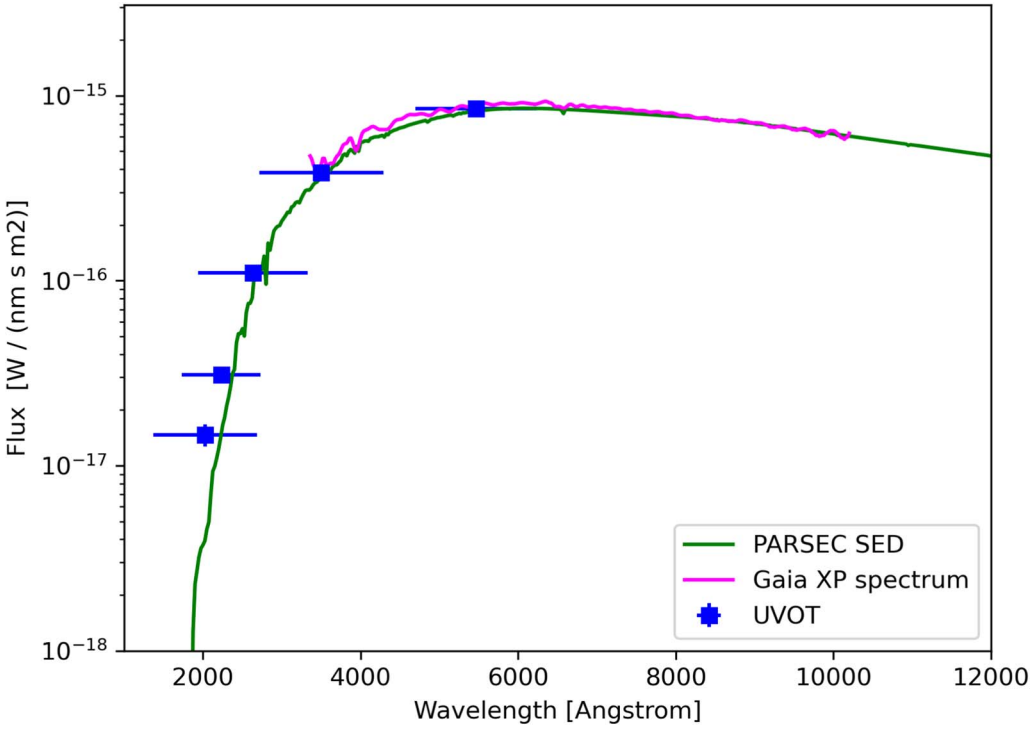


Figure 2. Gaia BH3 SED in the UV/optical bands. Green line: SED computed using the PARSEC libraries based on Gaia stellar parameters. Purple line: Gaia XP spectrum. Blue squares: UVOT data (the horizontal bars in wavelength represent the FWHM of the UVOT filters, as reported by T. S. Poole et al. 2008.)

In such a case the UV flux at ∼2200 Å would be <1% of the flux measured by us, which we attribute to the noncollapsed component.

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